Environmental Toxicology and Chemistry, Vol. 7, pp. 245-260, 1988
Printed in the USA. Pergamon Journals Ltd.

0730-7268/88 $3.00 + .00

POTENTIAL HAZARD TO EASTERN SCREECH-OWLS AND OTHER RAPTORS OF BRODIFACOUM BAIT USED FOR VOLE CONTROL IN ORCHARDS

PAUL L. HEGDAL*
Denver Wildlife Research Center, Animal and Plant Health Inspection Service,
U.S. Department of Agriculture, Denver, Colorado 80225-0266

BRUCE A. COLVIN
Department of Biological Sciences, Bowling Green State University,
Bowling Green, Ohio 43403

(*Received* 29 *December* 1986; *Accepted* 15 *September* 1987)

Abstract – During the fall and winter of 1981-82, a study was conducted to evaluate the secondary poisoning hazards associated with a proposed anticoagulant rodenticide, Volid® (10 ppm brodifacoum), when used to control voles (*Microtus* spp.) in apple orchards. Radio transmitters were attached to 38 eastern screech-owls (*Otus asio*), 5 barred owls (*Strix varia*), 3 red-tailed hawks (*Buteo jamaicensis*), 2 great horned owls (*Bubo virginianus*) and 2 long-eared owls (*Asio otus*), and the birds' movements were monitored before, during, and after rodenticide applications. Screech-owls selected woods over alternate habitats for day-roosting; 73% of daytime locations were in woods. At night, screech-owls generally were located in woods, orchard, and field-pasture proportional to their availability, while they avoided cropland. The home ranges of 32 screech-owls tracked posttreatment included brodifacoum-treated areas; the proportion of home range treated and habitat use varied among individuals. Minimum mortality was 58% among screech-owls for which more than 20% of home range was treated, as compared with 17% among those for which less than 10% of home range was treated. Secondary brodifacoum poisoning was the most probable cause of death in six screech-owls. Of five other screech-owls found dead posttreatment, four had been consumed by predators and one died of unknown causes. Of six radio-equipped screech-owls collected one to two months posttreatment, four contained detectable brodifacoum residue. The fate of 14 of the 32 screech-owls tracked posttreatment was unknown at the conclusion of radio-tracking efforts (63 d after treatment began) because radio contact was lost or the transmitter was dropped; one of these owls was encountered alive in May. Four barred owls tracked posttreatment showed strong selection for woodland habitat and used orchards limitedly; none was found dead posttreatment. One long-eared owl found dead (not radio-equipped) was probably killed by secondary brodifacoum poisoning. The results indicate a hazard to screech-owls and a potential risk to other raptors, given this use pattern and formulation of brodifacoum bait.

Keywords – Barred owl   Brodifacoum   Orchards   Rodenticide   Screech-owl   Secondary poisoning   Telemetry   Vole (*Microtus*)

INTRODUCTION

Microtine rodents often are agricultural pests. In apple orchards they girdle tree trunks and roots, especially during the winter [1]. Meadow vole (*Microtus pennsylvanicus*) and pine vole (*Microtus pinetorum*) are two of the more geographically widespread *Microtus* species in North America, and both can be highly destructive of apple trees [2,3]. Vole control practices in orchards include the use of rodenticide during the fall and winter [4]. Among the rodenticides currently registered for this use are an acute poison, zinc phosphide, and the anticoagulant rodenticides, diphacinone and chlorophacinone. Another anticoagulant rodenticide, brodifacoum, was evaluated by ICI Americas, Inc., for use against voles in dormant apple orchards and found to be efficacious [5]. However, the U.S. Environmental Protection Agency (EPA) indicated that a field study should be conducted to evaluate the potential hazards to raptors from this proposed use of brodifacoum bait.

*To whom correspondence may be addressed.

This work was conducted under the guidance of the U.S. Fish and Wildlife Service. The Center was transferred to the Animal and Plant Health Inspection Service on 3 March 1986.

Reference to trade names does not imply U.S. Government endorsement.

Secondary toxicity from anticoagulant rodenticides has been demonstrated in the laboratory in both birds and mammals [6–10]. Although a laboratory study may show that secondary poisoning can occur, field evaluations determine the likelihood of poisoning, given a rodenticide's toxicity and use pattern, the target species' bait consumption and behavior, and nontarget species' foraging behavior and habitat use. For example, Hegdal and Blaskiewicz [11] found it unlikely that common barn-owls (*Tyto alba*) would be at risk from the use of Talon® rodenticide (50 ppm brodifacoum) in baiting for commensal rodents on U.S. farmsteads. Colvin [12] found that common barn-owls selected grassland habitats for foraging, and selected certain-sized prey, particularly voles. Therefore, rodenticide used on farmsteads to control house mice (*Mus musculus*) and Norway rats (*Rattus norvegicus*) was not likely to affect barn-owl populations.

It is reasonable to propose that the anticoagulant rodenticides used to control voles might have secondary effects on raptors. Indeed, Craighead and Craighead [13] found that among all raptors studied, voles were the most common prey in the raptor diet. The diet of eastern screech-owls includes small mammals, birds, and insects [14–16]. Birds appear more commonly in screech-owl diets during the nesting season [15,17], while during the fall and winter (when rodenticide baiting in orchards is usually done), small mammals, especially voles, are the dominant prey [13,15,18].

The objective of this study was to evaluate the potential secondary hazard to eastern screech-owls and, to the extent possible, to other raptors from the use of Volid* (an experimental bait with 10 ppm brodifacoum) in controlling voles in dormant apple orchards. The screech-owl was chosen as the indicator species because it uses open field-woodland edge habitats, has a fall-winter diet of voles and is relatively common (so that adequate numbers could be captured) and because it was found to suffer secondary poisoning in a limited pilot study [19].

METHODS

Study area

The study area, approximately 150 km^2, consisted of 15 orchard areas treated in the Shenandoah Valley near Winchester, Frederick County, Virginia. Topographically, the land consisted of rolling hills, and elevation varied between 200 and 350 m above sea level. Apple production is one of the principal agricultural activities, and corn, grain and alfalfa fields, and pasture occur in a patchwork pattern with orchards. Patches of deciduous woods are common. Vole damage in apple orchards is a serious problem, and rodenticides are used each year. Each of the 15 areas chosen was located near screech-owl habitat (i.e., woodland), and contained a vole population adequate to justify treatment.

Capture techniques

Raptors were captured from 25 October to 17 December 1981. Several techniques were used to maximize opportunities for capturing various raptor species and age classes, and also both sexes.

Screech-owls often roost in cavities, such as nest boxes, especially after leaf drop in the fall, and thus boxes were used to capture roosting owls. The box used was approximately 28 cm wide, 23 cm deep and 50 cm high, with an 8-cm-diameter hole cut near top-center in the front. In late August 1981, 125 of these boxes were placed on trees along the perimeter of the woodlots adjoining 10 orchards that had been selected for Volid treatment. In October 1981, 19 boxes were placed along the perimeter of another orchard. The boxes usually were placed within 10 m of the orchard edge; none was more than 30 m from the orchard. They were attached to trees with a copper strap about 4 m from the ground and were spaced about 50 m apart. Each box was checked for roosting screech-owls at least every other day in the early phases of the study.

Mist nets (10.2 cm mesh) were set in and adjacent to orchards, and tape-recorded calls of screech-owls were played at night to attract owls to the nets. The nets were 9.1, 12.8, and 18.3 m long and were set in a variety of formations from vees to squares to right angles. For extra height, they sometimes were used in double tiers; with single-tier nets, 1.5-m pieces of conduit (1.3 cm diameter) were used as extensions on the ends of the 3-m poles (1.9 cm diameter), to which nets were attached. Recordings of local screech-owls were made using a Uher tape recorder and a 61-cm aluminum parabolic reflector that could be either hand-held or mounted on a mast extending through the roof of a vehicle.

Tape-recorded distress calls of mice and rabbits on continuous-loop 8-track cassettes, or live-bait animals [rock doves (*Columba livia*), Norway rats, or house mice] tethered or placed in cages or bal-

*Volid (ICI Amencas, Inc., Wilmington, DE) is not registered by the EPA for use in the U.S.

chatri traps [20,21], also were used to lure owls to the mist-net sets. Verbail traps [22] were set on posts in and around the orchards; tethered or caged animals frequently were placed near them. Three Swedish goshawk traps [23] baited with rock doves and a net trap that tripped to form a net tent (baited with caged rats, mice, or rock doves) also were employed.

In late May 1982, recapture of each of the previously radio-equipped screech-owls (that still could have been present) was attempted. All screech-owl boxes were checked for nesting owls, and mist nets and screech-owl recordings were used on two or three nights within the known territory of each owl.

Radiotelemetry and habitat characterization

Radio transmitters were designed and built by the Bioelectronics Unit, Section of Supporting Sciences, Denver Wildlife Research Center. They were in the 164 MHz band on the 12 U.S. Fish and Wildlife Service assigned channels. All transmitters were designed for tail-feather attachment with hot-melt glue [24,25]. Since brodifacoum is an anticoagulant, we were concerned that other attachment methods (harness, poncho, glue on skin, or tarsi attachment) might cause irritation or hemorrhage and possibly influence the results of the study. Ten transmitters (14 g) designed for larger raptors (e.g., great horned owl) and 15 transmitters (8 to 9 g) designed for screech-owls contained a mortality circuit (the transmitter changed pulse rate if it remained motionless for about 45 min). All other screech-owl transmitters were single-pulse-rate transmitters and weighed about 7 g. With vehicle-mounted receiving equipment and an owl in a daytime roost, the transmitters generally had a range of 2 to 4 km. However, if a transmitter was lying on the ground, the range could be shortened to 0.5 km.

Radio-tracking vehicles initially were equipped with roof-mounted, dual yagi antennas mounted in a vertical plane and a single yagi antenna mounted in a horizontal plane [11,26]. Later, because the antennas got caught in branches in and around orchards, only the single yagi was used. These antennas could be rotated from inside the vehicles, and radio bearings were indicated on a 360-degree, 25-cm protractor by a pointer attached to the antenna mast [27]. Hand-held antennas were employed when afoot.

Model LA-12 receivers (built by AVM) were used for all radio-tracking. A pulse interval counter (built by AVM) was used to assist in determining transmitter pulse rates and thus animal identification.

There was radio-voice communication equipment in each vehicle for use in coordinating tracking efforts. Bearings could be taken simultaneously by different vehicles and radioed to one vehicle equipped with a plotting table. Bearings were plotted in the field on aerial photographs (scale 1:7920, 1 cm = 79.2 m), and these locations were then recorded as universal transverse Mercator (UTM) coordinates to the nearest 100-m grid [26].

Radio-tracking was begun 25 October 1981 when the first transmitter was put on an owl and continued through 22 January 1982. During the initial phases of the study, the efforts to capture owls prevented intensive radio-tracking, especially at night. However, an attempt was made daily to locate the roosting site of each owl. After most transmitters were on the owls, an attempt also was made each night to locate sites the owls frequented. Those owls with mortality transmitters only had to be heard for their status to be determined (dead or alive); those with regular transmitters had to be visually observed. If possible, all screech-owls were located daily, especially post-treatment, to determine their status and daytime roosting site. Individual owls were radio-tracked in a random fashion at night rather than continuously, and thus night observations were independent and reflected time owls spent in various habitats and not necessarily the frequency with which they entered each habitat.

All habitats within and around the home range of each owl were classified by vegetative type, and the hectares of brodifacoum-treated orchard and other habitats were calculated. Because of the limited availability and use by the owls of some habitats within some home ranges, the habitats were grouped into major categories: woods, orchard, cropland (corn stubble, tilled, grain, hay), field-pasture (old field, grassland), and rural residential. Grouping increased radio-tracking sample sizes per habitat category, and thus enhanced the power of the statistical tests.

Using chi-square, observed habitat use was compared with expected use based on habitat availability within the home range of each owl. This was done separately with each owl's day and night radiotelemetry data to evaluate randomness of habitat use. Differences in habitat use between owl species also were evaluated by chi-square. The owls' habitat selection was evaluated with the electivity index of Ivlev [28], using the percentage of each of the five habitat categories within the home range of an owl and the percentage of all radiotelemetry data for the same owl recorded in each of those habitats. Selection indices could range from +1 to −1, with +1 being most selected.

Treatment

Starting on 9 November 1981, the orchards were treated with Volid by personnel from the Winchester Fruit Research Laboratory in accordance with an EPA experimental use permit (EUP No. 10182-EUP-21). The pelletized, grain-based bait containing 0.001% brodifacoum was broadcast with ground equipment at a rate of approximately 16.8 kg/ha (15 lb/acre). This was equivalent to 168 mg of active ingredient (brodifacoum) per hectare. In addition, several orchards were treated with Volid at a level of approximately 11.2 kg/ha (10 lb/acre) by the orchardists under an experimental use permit.

All Volid applications were completed by 3 December 1981. In all, approximately 450 ha of orchard was treated. Other rodenticide bait containing zinc phosphide was used on some orchards nearby, and a few of the brodifacoum-treated orchards also were treated with zinc phosphide by Winchester Fruit Laboratory personnel. The anticoagulant chlorophacinone (Rozol®, Chempar Chemical Corp., New York, NY) was used very limitedly in the vicinity of the study area.

Necropsy and residue analysis

All screech-owls and other animals collected or found dead were labeled, individually packaged in plastic bags, and frozen for necropsy and residue analysis. All carcasses were assigned random numbers by field personnel and thus were necropsied and analyzed for chemical residues as unknowns.

Necropsies were conducted on 17 February 1982 with the assistance of ICI Americas, Inc., personnel at Goldsboro, North Carolina. Residue analyses were conducted by Analytical Biochemistry Laboratories Inc. (Columbia, MO) using the ICI Americas, Inc., HPLC method for brodifacoum determination in animal tissue [29]. The limit of brodifacoum detection was 0.3 ppm for liver and 0.1 ppm for all other samples.

RESULTS

Screech-owl mortality

Thirty-eight screech-owls were captured and radio-equipped from October through December 1981. Nineteen were captured using mist nets and screech-owl recordings; 12 by checking boxes; and the remaining 7 with mist nets, with or without bait or lure. Of these 38 owls, only 32 (Nos. 7 to 38) potentially were exposed to Volid. The other six had lost their transmitters, could not be located or were killed before exposure to Volid (Table 1).

Posttreatment, 11 radio-equipped screech-owls (Nos. 7-17) were found dead (Table 1). Levels of brodifacoum residue ranging from 0.4 to 0.8 ppm were detected in the livers of five of these owls (Table 2); extensive hemorrhaging was found in six (Nos. 7-12) and was most severe in those five with detectable residue (Nos. 8-12). One owl (No. 13) had neither residue nor distinct hemorrhaging. The remaining four screech-owls (Nos. 14-17) were found after they had been mostly consumed by a predator (most probably avian) and thus no carcass was available for necropsy or residue analysis.

Necropsy observations in owl Nos. 7 to 12 included hemorrhaging on the head, neck, shoulders, legs, and in pleural and abdominal cavities. Pale-colored livers also were noted. One screech-owl (No. 9) had a severe discharge of blood from the cloaca; it appeared that the blood had drained from internal organs.

Three principal criteria were used to evaluate secondary poisoning in the 11 dead screech-owls: (a) radiotelemetry data, including the amount of treated area within the home range, presence in the treated area posttreatment, use of orchard habitat, and duration and outcome of radio-tracking (survival, mortality); (b) necropsy data, including presence or absence of hemorrhaging and general physical condition; and (c) residue present in liver or carcass. Other information was used when available, including residue analysis of owl pellets, field observations and reports from landowners. These criteria were considered independently and then collectively; sufficient data were available for only 7 of the 11 screech-owls (Nos. 7-13). Secondary poisoning from brodifacoum was the most probable cause of death for screech-owl Nos. 7 to 12 but not for screech-owl No. 13 (Table 1).

During early January 1982 (between 31 and 57 d posttreatment), six screech-owls (Nos. 18-23) were recaptured for residue analysis. Although previously radio-equipped, none of the owls had an operational transmitter at the time of capture. Each owl appeared alert and normal and all were in good physical condition. In four of these birds (Nos. 19-22), detectable brodifacoum residue was present in the liver, from 0.3 ppm to 0.6 ppm (Table 2).

Of the remaining 15 screech-owls captured (Nos. 24-38), 11 had lost their transmitter (along with the central tail feathers in 10 cases) and radio contact was lost with 3 others (Table 1). At least 11 of these birds were located by radiotelemetry in brodifacoum-treated areas posttreatment. The re-

Table 1. Radio-tracking results for eastern screech-owls in brodifacoum secondary hazard study in Frederick County, Virginia (fall and winter 1981–82)

Owl No.	No. of days tracked	Period tracked	Treatment date	No. of days posttreatment	Results
1	6	27 Oct–2 Nov.	—	—	Killed by vehicle pretreatment
2	10	8–19 Dec.	—	—	Transmitter came off tail feathers
3	10	30 Oct.–9 Nov.	—	—	Transmitter pulled off; snagged in tree cavity
4	3	3–6 Nov.	—	—	Transmitter fell off; bird recaptured pretreatment but killed in mist net by long-eared owl
5	1	29–30 Oct.	—	—	Lost radio contact
6	10	19–29 Nov.	—	—	Captured away from study area; relocated but left area before treatment; killed by vehicle
7	10	4–22 Nov.	17 Nov.	5	Found dead 0.2 km from a brodifacoum-treated orchard (apparently brodifacoum poisoning)
8	26	16 Nov.–12 Dec.	29 Nov.	13	Found dead less than 0.2 km from a brodifacoum-treated orchard (apparently brodifacoum poisoning)
9	23	29 Nov.–22 Dec.	4 Dec.	18	Found dead less than 0.1 km from a brodifacoum-treated orchard (apparently brodifacoum poisoning)
10	5	27 Nov.–2 Dec.	9, 27–30 Nov.	23, 5	Found dead in a brodifacoum-treated orchard (apparently brodifacoum poisoning)
11	34	14 Nov.–18 Dec.	17 Nov.	31	Found dead 0.2 km from a brodifacoum-treated orchard; partially consumed by a predator (apparently brodifacoum poisoning)
12	32	19 Nov.–21 Dec.	17 Nov.	34	Found dead 0.3 km from a brodifacoum-treated orchard (apparently brodifacoum poisoning)
13	44	9 Nov.–23 Dec.	16 Nov.	37	Found dead 1.2 km from a brodifacoum-treated orchard (apparently not brodifacoum poisoning)
14	33	16 Nov.–19 Dec.	30 Nov.	19	Feathers only found less than 0.1 km from a brodifacoum-treated orchard; consumed by a predator[a]
15	17	12–29 Nov.	9, 27–30 Nov.	20, 2	Feathers only found less than 0.1 km from a brodifacoum-treated orchard; consumed by a predator[a]
16	23	19 Nov.–12 Dec.	18 Nov.	24	Feathers only found less than 0.1 km from a brodifacoum-treated orchard; consumed by a predator[a]
17	11	14–25 Dec.	20 Nov.	35	Feathers only found less than 0.1 km from a brodifacoum-treated orchard; consumed by a predator[a]
18	18	16 Nov.–4 Dec.	3 Dec.	1	Molted tail feathers and transmitter; collected in a brodifacoum-treated orchard (6 Jan.) for residue analysis
19	50	14 Nov.–3 Jan.	30 Nov.	34	Molted tail feathers and transmitter; collected 0.2 km from a brodifacoum-treated orchard (12 Jan.) for residue analysis
20	40	15 Nov.–25 Dec.	18 Nov.	37	Lost radio contact; collected 0.8 km from a broadifacoum-treated orchard (9 Jan.) for residue analysis
21	35	20 Nov.–25 Dec.	16 Nov.	39	Transmitter came off tail feathers; collected 0.3 km from a brodifacoum-treated orchard (12 Jan.) for residue analysis

continued

Table 1 continued.

Owl No.	No. of days tracked	Period tracked	Treatment date	No. of days posttreatment	Results
22	44	8 Nov.–22 Dec.	9, 27–30 Nov.	43, 19	Molted tail feathers and transmitter; collected in a brodifacoum-treated orchard (4 Jan.) for residue analysis
23	54	14 Nov.–7 Jan.	18 Nov.	50	Lost radio contact; collected in a brodifacoum-treated orchard (9 Jan.) for residue analysis
24	8	15–23 Nov.	20 Nov.	3	Molted tail feathers and transmitter
25	16	4–20 Nov.	13 Nov.	7	Molted tail feathers and transmitter
26	19	29 Nov.–18 Dec.	4 Dec.	14	Lost radio contact
27	22	14 Nov.–6 Dec.	17 Nov.	19	Molted tail feathers and transmitter
28	32	17 Nov.–19 Dec.	30 Nov.	19	Molted tail feathers and transmitter
29	4	7–13 Dec.	9, 27–30 Nov.	28, 10	Transmitter pulled off; snagged in tree cavity
30	20	8–28 Dec.	29 Nov.	29	Molted tail feathers and transmitter
31	16	12–28 Dec.	29 Nov.	29	Molted tail feathers and transmitter
32	40	12 Nov.–22 Dec.	13 Nov.	39	Molted tail feathers and transmitter
33	42	15 Nov.–27 Dec.	18 Nov.	39	Lost radio contact
34	50	10 Nov.–30 Dec.	16 Nov.	44	Molted tail feathers and transmitter
35	47	11 Nov.–28 Dec.	9, 27–30 Nov.	49, 25	Molted tail feathers and transmitter
36	24	17 Dec.–10 Jan.	16 Nov.	55	Molted tail feathers and transmitter
37	61	25 Oct.–25 Dec.	13 Nov.	42	Lost contact; nested in next box in May 1982
38	41	13 Dec.–22 Jan.	20 Nov.	63	Operating transmitter at end of tracking period

All owls tracked posttreatment had brodifacoum-treated orchard in their home range.
[a]Involvement of brodifacoum unknown; no carcass available for necropsy or residue analysis.

maining owl (No. 38) was still carrying an operating transmitter on the last day of radio-tracking, 22 January 1982.

During May 1982, there could have been a maximum of 18 of the previously radio-equipped screech-owls still alive in the study area (including three owls with which contact was lost pretreatment). Spring capture efforts resulted in 13 captures of nine different screech-owls; only one owl (No. 37) had been previously radio-equipped.

Screech-owls and treated areas

About 57% of orchard habitat, averaged among the home ranges of 32 screech-owls, was treated with brodifacoum. Availability of brodifacoum-treated habitat to individual screech-owls was highly variable, ranging from 2.8 to 48.6 ha, equivalent to 4 to 44%, of the home range for any one owl (Table 3). The percentage of home range that was treated with brodifacoum was high for the six owls (Nos. 7–12) classified as brodifacoum mortalities, as compared with the percentages for most of the other screech-owls. Five of the six had more than 20% of their home range treated with brodifacoum; however, only one (No. 12) had a positive selection index for orchard.

Owl No. 13, found dead but not classified as a brodifacoum mortality, had only 4% of its home range treated with rodenticide (all by brodifacoum). Of the four owls consumed by predators, two (Nos. 15 and 16) had a relatively high proportion of their home range treated with brodifacoum (36 and 29%, respectively); owl No. 16 also had a strong selection index for orchard (Table 3).

Of the six owls collected for residue analysis, only No. 22 had a relatively high proportion of its home range treated with brodifacoum (34%); others had 8 to 12% of their home range treated. Owl No. 22 was one of four that contained residue, but it was the only one with distinct internal hemorrhaging. Of the 15 remaining screech-owls, 4 (Nos. 24, 29, 32, and 36) had more than 20% of their home range treated, and 9 had less than 10% treated.

Screech-owl habitat use

The mean home ranges for the screech-owls were calculated using minimum area polygons determined with radiotelemetry. There was a highly significant relationship between the number of data points recorded and home range size for those owls for which there were relatively few observa-

Table 2. Summary of residue analyses for 16 eastern screech-owls collected or found dead during the brodifacoum secondary hazard study in Frederick County, Virginia (fall and winter 1981-82)

Owl No.	No. of days posttreatment	Residue (ppm) Carcass	Residue (ppm) Liver
1	—	ND	ND
4	—	ND	ND
6	—	ND	ND
7	5	ND	ND
8	13	ND	0.5
9	18	LA	0.4
10	23, 5	ND	0.8
11	31	LA	0.5
12	34	ND	0.5
13	37	ND	ND
18	34	ND	ND
19	43	ND	0.6
20	51	ND	0.3
21	57	ND	0.4
22	55, 31	ND	0.3
23	52	ND	ND

ND, none detected at a limit of determination of 0.3 ppm for liver and 0.1 ppm for carcass; LA, lost in analysis.

tions. However, such a relationship disappeared when 35 or more data points were recorded per owl ($r = 0.293$, 17 *df*, $p > 0.05$). Therefore, the average screech-owl home range size was based on the 19 owls for which there were 35 or more data points, and the mean home range was 134.0 ± 86.3 ha (range, 54.0 to 387.7 ha). For these 19 screech-owls, an average of 25% of the home range was orchard (range, 4 to 44%) (Table 4).

There were 1,463 locations recorded by habitat type for all radio-tracked screech-owls (Table 5). The distribution of observations among five habitat categories during the day was significantly different from that observed at night ($\chi^2 = 294.060$, 4 *df*, $p < 0.001$). Day roosts in the woods were inside tree cavities, on tree limbs (against the tree trunk or totally exposed on a limb), or in dense, brushy vegetation such as honeysuckle (*Lonicera* sp.); the roost heights ranged from zero (on the ground) to about 10 m above the ground. Other day roosts were in residential areas, most often in trees in yards but occasionally within, or under the eaves of, buildings (e.g., barn, garage). Day roosts observed in other habitats (orchard, field-pasture, cropland) were in single trees within or bordering fields or in dense vegetation in fencerows. In at least one instance, an owl day-roosted on the ground in a corn-stubble field.

The screech-owls' selection of habitat for day-roosting was highly nonrandom (Table 6), and there was significant variation among owls in their choice of day roosts (χ^2 heterogeneity = 512.531, 40 *df*, $p < 0.001$). Selection indices (E), calculated according to the method of Ivlev [28], showed that screech-owls strongly preferred the woods for day-roosting (Table 7). Other habitats were used far less frequently than would be expected on the basis of their availabilities. The only exception was rural residential habitat; two screech-owls selected this habitat over woods, and three others had positive selection indices for it.

At night, screech-owls were not as selective in their use of habitats as they were in the day, although χ^2 values were still significant ($p < 0.05$) for 12 of 20 owls (Table 6). There also was significant variation in habitat use at night among individual screech-owls (heterogeneity $\chi^2 = 102.332$, 54 *df*, $p < 0.001$). Although selection indices for woods, orchard and field-pasture at night varied among individuals, habitat use appeared relatively random based on average E values (Table 7). In the night location data, 13 of 20 screech-owls had positive E values for woods, 8 of 19 had positive values for orchard and 7 of 19 had positive values for field-pasture. Of those owls for which selection indices could be calculated for both orchard and field-pasture (vole habitat), 67% (12 of 18) had positive E values for either orchard or field-pasture, or both. Cropland was used at night by all screech-owls far less frequently than would be expected on the basis of its availability. Seven of eight screech-owls had positive E values for residential areas at night, which may reflect the use of trees in residential areas as night roosts between foraging bouts.

Significant χ^2 heterogeneity values suggest behavioral differences among screech-owls with respect to habitat use. These differences may have been accentuated by the differing proportions of various habitats in each home range, and thus by the different combinations from which an owl could choose. Variation in selection indices (E) among the owls can be interpreted similarly.

Other raptors

Five barred owls, two great horned owls, two long-eared owls, and three red-tailed hawks were captured and radio-equipped during October through December 1981. Twenty-one other raptors were captured but not radio-equipped because they were presumed to be migrants [four American kestrels (*Falco sparverius*), four northern saw-whet owls (*Aegolius acadicus*) and five red-tailed hawks]

Table 3. Availability of brodifacoum-treated orchard within the home ranges of 32 eastern screech-owls and 4 barred owls radio-tracked posttreatment in Frederick County, Virginia (fall and winter 1981–82)

	Home range			
Owl No.	Orchard (ha)	Brodifacoum-treated (ha)	Percent brodifacoum-treated	Selection index (E),[a] orchard (night)
Screech-owls				
7	46.3	17.8	11.5	—
8	17.8	17.8	44.4	−0.10
9	10.1	8.9	31.1	−0.17
10	75.7[b]	37.2	27.8	—
11	49.6	43.9	35.9	−0.10
12	30.2	29.6	21.3	+0.26
13	7.0	7.0	4.2	NC[c]
14	5.7	2.8	5.2	−0.19
15	67.2[b]	48.6	36.3	—
16	36.8	33.0	29.0	+0.30
17	38.4[b]	17.8	13.3	—
18	14.8[b]	14.8	11.0	—
19	31.5	10.1	11.8	−0.13
20	46.0	32.2	8.3	−1.00
21	8.3	7.1	12.0	−0.04
22	29.6	22.7	33.8	+0.05
23	95.6	28.0	12.3	+0.18
24	58.7[b]	38.9	29.0	—
25	5.1[b]	5.1	3.8	—
26	17.6[b]	10.5	7.8	—
27	21.7[b]	13.2	9.9	—
28	36.1	9.9	8.4	+0.13
29	51.4[b]	38.0	28.4	—
30	11.0[b]	6.3	4.7	—
31	20.0[b]	10.9	8.1	—
32	19.2	19.2	21.1	−0.23
33	60.5	27.7	14.8	+0.12
34	18.5	3.2	4.8	+0.05
35	50.3	28.9	35.7	−0.17
36	13.6	7.1	5.7	−0.13
37	24.5	7.2	2.5	+0.45
38	48.0	6.9	10.5	−0.21
Barred owls				
40	66.4	19.0	3.4	−1.00
41	87.5	36.8	7.7	−0.32
42	100.4	57.6	22.3	−0.33
43	94.7	34.9	3.6	−0.07

[a] E calculated according to the method of Ivlev [28]. Values were calculated only for owls for which 20 or more data points were recorded at night. E can range from +1 to −1, with +1 being most selected.
[b] When fewer than 20 data points were recorded for screech-owls at night, the mean screech-owl home range (134 ha) was used and a 650-m radius drawn from the center of activity (except when the calculated home range exceeded 134 ha).
[c] E not calculated because orchard constituted less than 5% of home range and less than 10% of owl habitat use.

and/or because they feed mostly on birds [five sharp-shinned hawks (*Accipiter striatus*), three Cooper's hawks (*Accipiter cooperii*)].

Four of five barred owls were tracked posttreatment. All four had brodifacoum-treated orchard within their home ranges, and three were tracked in brodifacoum-treated orchard. Radio contact was lost with the fifth barred owl pretreatment. No barred owls were found dead posttreatment. One molted its tail feathers and the attached radio 42 d posttreatment; the other three were alive, appeared well and had operating transmitters on the last day of tracking, 22 January 1982 (53, 53, and 67 d posttreatment, respectively, for each owl).

Table 4. Mean habitat composition of home ranges of 19 eastern screech-owls and 4 barred owls in Frederick County, Virginia (fall and winter 1981-82)[a]

	Percentage of home range	
Habitat	Screech-owl	Barred owl
Woods	25.7	29.6
Orchard	24.8	19.7
Cropland	23.2	10.7
Field-pasture	18.8	35.7
Rural residential	7.5	4.3

[a]Only owls for which 35 or more total data points were recorded with radiotelemetry were used.

Radio contact was lost with both radio-equipped great horned owls (on the day of treatment and 8 d posttreatment); they probably damaged the radio transmitter sufficiently to interfere with transmission. Radio contact was lost with the two long-eared owls and three red-tailed hawks within 5 d of attaching the transmitters, 0 to 14 d pretreatment; they most likely were migrants.

On 5 January 1982, an orchardist informed us that he had found a dead long-eared owl on his farmstead on about 20 December 1981. This site was less than 50 m from an orchard treated with brodifacoum on 27 to 30 November; there were 54 ha of brodifacoum-treated orchard (and no other anticoagulant-treated orchard) within 1 km of the farm. The carcass, and also several owl pellets containing vole remains, were retrieved from this farmstead, where two long-eared owls had frequently day-roosted during the fall. The orchardist reported that the dead owl had hemorrhaged, apparently from the head, when it was found, dead. Severe hemorrhage was noted at necropsy; tissue analysis showed no detectable brodifacoum residue in the liver or the rest of the body. Residue analysis of five samples of owl pellets showed that one contained 0.42 ppm brodifacoum. We believe the most probable cause of death for this long-eared owl was secondary brodifacoum poisoning.

As indicated by the capture of 33 different individuals representing eight raptor species (in addition to the 38 screech-owls), orchards and bordering habitats were used by numerous raptors. The raptors were potentially exposed to secondary brodifacoum poisoning through feeding on microtine rodents and nontarget animals such as birds and cottontail rabbits (*Sylvilagus floridanus*). Three dark-eyed juncos (*Junco hyemalis*) found dead and one captured in poor condition, between 8 and 56 d posttreatment in treated orchards, had whole-carcass residues ranging from 0.14 to 0.62 ppm brodifacoum; none was detected in a junco trapped 5 d posttreatment in a treated orchard. Of three cottontail rabbits taken from treated orchards and analyzed for liver residue, one had 0.3 ppm brodifacoum (found moribund 28 d posttreatment, severe rectal bleeding and internal hemorrhage) and two had none (one found dead 7 d posttreatment, slight internal hemorrhage; one trapped 14 d posttreatment, severe internal hemorrhage), at a level of detection of 0.3 ppm.

Barred owl habitat use

Minimum home ranges calculated for the four barred owls tracked extensively ranged from 258.9 to 979.6 ha (mean, 567.8 ha). An average of 20% (range, 10 to 39%) of home range was orchard for these owls (Table 4); habitat composition in the barred owl home ranges was significantly different from that observed for screech-owls ($\chi^2 = 26.675$, 4 df, $p < 0.001$).

Table 5. Frequency with which 37 eastern screech-owls and 5 barred owls were located with radiotelemetry in various habitat types in Frederick County, Virginia (fall and winter 1981-82)

	Screech-owls						Barred owls					
	Day		Night		Total		Day		Night		Total	
Habitat	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Woods	466	72.5	277	33.8	743	50.8	145	86.3	106	52.7	251	68.0
Orchard	46	7.2	258	31.5	304	20.8	4	2.4	19	9.5	23	6.2
Cropland	7	1.1	79	9.6	86	5.9	0	0.0	12	6.0	12	3.3
Field-pasture	43	6.7	142	17.3	185	12.6	18	10.7	59	29.4	77	20.9
Rural residential	81	12.6	64	7.8	145	9.9	1	0.6	5	2.5	6	1.6
Total	643		820		1,463		168		201		369	

Table 6. Results of chi-square tests to evaluate habitat use by 20 radio-equipped eastern screech-owls in Frederick County, Virginia (fall and winter 1981-82)

Owl no.	Day: No. of data points	Day: χ^2	Day: *df*	Day: *p*	Night: No. of data points	Night: χ^2	Night: *df*	Night: *p*
8	<20	—	—	—	22	7.132	2	0.05
9	<20	—	—	—	20	3.697	3	NS
11	26	72.561	3	0.001	30	0.767	3	NS
12	27	254.232	3	0.001	27	17.193	3	0.001
13	32	5.433	2	NS	39	2.613	2	NS
14	<20	—	—	—	28	8.454	3	0.05
16	<20	—	—	—	20	7.257	3	NS
19	33	95.216	3	0.001	46	14.291	3	0.005
20	28	69.494	3	0.001	34	8.861	3	0.05
21	29	8.838	3	0.05	31	0.257	3	NS
22	22	84.140	3	0.001	37	7.746	3	NS
23	43	79.813	3	0.001	51	11.863	3	0.01
28	<20	—	—	—	25	2.927	3	NS
32	33	49.962	3	0.001	30	18.703	3	0.001
33	28	85.504	3	0.001	34	11.325	3	0.025
34	36	25.274	3	0.001	36	9.010	3	0.05
35	25	18.235	2	0.001	45	8.732	2	0.025
36	23	26.236	3	0.001	24	6.482	3	NS
37	44	19.049	3	0.001	39	10.971	3	0.025
38	37	116.761	3	0.001	38	22.168	3	0.001
χ^2 total		1,010.748	43	0.001		180.449	57	0.001
χ^2 pooled		498.217	3	0.001		78.117	3	0.001
χ^2 heterogeneity		512.531	40	0.001		102.332	54	0.001

Four habitat groups were used in the analysis: woods, orchard, cropland and other (field-pasture, rural residential). Significant chi-square values indicate nonrandom use of available habitats. Only owls for which there were 20 or more data points were used. NS, not significant.

There were 369 locations recorded by habitat type among the radio-tracked barred owls (Table 5). The distribution of observations among the five habitats during the day was significantly different from that observed at night ($\chi^2 = 49.788$, 4 *df*, $p < 0.001$) and was also significantly different from that observed for screech-owls at night ($\chi^2 = 65.355$, 4 *df*, $p < 0.001$) and during the day ($\chi^2 = 29.707$, 4 *df*, $p < 0.001$). Eighty-six percent of day locations and 53% of night locations were in woods; only 10% of barred owl night locations were in orchards.

The use of available habitats by barred owls was highly nonrandom, particularly for day-roosting (Table 8). As with screech-owls, there was significant variation in habitat use among barred owls. For day-roosting, all barred owls selected woods and showed strong avoidance of other habitat types (Table 7). At night, all barred owls maintained a strong preference for woods; orchard, cropland and rural residential areas were used far less frequently than would be expected by chance alone. Two barred owls had night selection indices for field-pasture that approached zero. About 42% of the orchard, averaged among the home ranges of the four barred owls, was treated with brodifacoum (Table 3). Brodifacoum-treated orchard ranged from 19.0 to 57.6 ha, equivalent to 3 to 22%, of individual barred owl home ranges.

DISCUSSION

Radiotelemetry

Some screech-owls lost their transmitters prematurely. Although we initially were concerned about the possibility of irritation, the use of harness attachment would have been helpful in determining the final posttreatment status of the radio-equipped population. The average period of radio contact (pre- and posttreatment) with screech-owls that were not found dead (n = 25) was 28 d (range, 1 to 61 d). Of the 13 screech-owls exposed to treatment and not accounted for at the end of the study, 9 were tracked for fewer than 30 d posttreatment (3 for fewer than 15 days). Of particu-

Table 7. Habitat selection indices (day and night) averaged for 20 eastern screech-owls and 4 barred owls radio-tracked in Frederick County, Virginia (fall and winter 1981–82)

	Habitat selection index (E)[a]				
	Woods	Orchard	Cropland	Field-pasture	Rural residential
Screech-owls					
Day	+0.35	−0.76	−0.89	−0.69	−0.14
	(15)	(14)	(11)	(14)	(8)
Night	+0.06	−0.05	−0.44	0.00	+0.31
	(20)	(19)	(16)	(19)	(8)
Barred owls					
Day	+0.50	−0.76	−1.00	−0.57	−0.76
	(4)	(4)	(4)	(3)	(2)
Night	+0.31	−0.43	−0.45	−0.17	−0.54
	(4)	(4)	(4)	(3)	(2)

[a] E calculated according to the method of Ivlev [28]. Number of owls in parentheses. Only owls for which there were 20 or more data points were used. E was not calculated for individual owls and habitats when the habitat was not available in the owl's home range or when it constituted less than 5% of the owl's home range and less than 10% of the owl's habitat use. E can range from +1 to −1, with +1 being most selected.

Table 8. Results of chi-square tests to evaluate habitat use by four radio-equipped barred owls in Frederick County, Virginia (fall and winter 1981–82)

	Day				Night			
Owl No.	No. of data points	χ^2	df	p	No. of data points	χ^2	df	p
40	30	40.718	3	0.001	32	17.310	3	0.001
41	42	39.168	3	0.001	64	4.425	3	NS
42	40	167.748	3	0.001	41	66.104	3	0.001
43	53	61.426	3	0.001	59	8.489	3	0.05
χ^2 total		309.060	12	0.001		96.328	12	0.001
χ^2 pooled		211.478	3	0.001		36.989	3	0.001
χ^2 heterogeneity		97.582	9	0.001		59.339	9	0.001

Four habitat groups were used in the analysis: woods, orchard, cropland and other (field-pasture, rural residential). Significant chi-square values indicate nonrandom use of available habitats. NS, not significant.

lar interest are three owls (Nos. 24, 29, and 35) that also had high exposures to treated orchards in their home ranges. Because screech-owls that most probably died of secondary brodifacoum poisoning were found up to 34 d posttreatment (mean, 21 d; range, 5–34 d), some of the screech-owls tracked for fewer than 34 d posttreatment, and subsequently not observed, may have been affected by secondary poisoning.

Additionally, when only the feather remains of an owl consumed by a predator were available (owl Nos. 14–17), the involvement of brodifacoum could not be determined. Death may have been from predation, scavenging may have occurred after the bird died from secondary poisoning, or predation may have been the proximate cause of death with secondary poisoning the ultimate cause (predation occurring because the owl was in a weakened condition).

It cannot be assumed that any of the missing screech-owls or predator-consumed owls were killed by secondary poisoning. However, considering all the screech-owl mortality that could be documented (given radio-tracking limitations), the minimum mortality was 58% among those screech-owls for which more than 20% of the home range was treated (n = 12, mean = 31% of home range treated), as compared with 17% among screech-owls for which less than 10% of their home range was treated (n = 12, mean = 6% of home range treated). We believe that screech-owls for which more than 20% of the home range was treated were at considerable risk and that the potential hazard was much lower for screech-owls for which less than 10% of their home range was treated. Seven screech-owls, other than those found dead, fell into the high-exposure category (two consumed by predators, one collected for residue analysis and four with which we lost contact).

Necropsy results

The observations of internal hemorrhaging in the six screech-owls believed to have died from brodifacoum poisoning are symptomatic of anticoagulant poisoning [8,30,31]. Otherwise, these owls (Nos. 7–12) were in good physical condition and, except for one, intact when found, thereby excluding predation or malnutrition as the cause of death. In contrast, owl No. 13 was intact but in poor physical condition and showed no major hemorrhaging; its condition was not consistent with brodifacoum-related mortality.

Residue analysis

The relationship between the dose of brodifacoum, its retention in tissue, including the liver, and the significance of this retained dose for the coagulation system is complex, varies among individuals and is poorly understood. The significance of the magnitude of the residues in the livers of screech-owls is, therefore, difficult to interpret other than to note that the presence of a detectable brodifacoum residue and evidence of extensive hemorrhaging are symptomatic of brodifacoum poisoning.

The level of residue detection in this study, however, was inadequate. That brodifacoum residue was not found when 0.3 ppm was used as the lower limit of detection in the liver does not exclude possible brodifacoum poisoning. Wildlife mortalities have been attributed to brodifacoum poisoning when there was less than 0.3 ppm residue in the liver; detection levels used to evaluate such mortalities were as low as 0.05 ppm [31]. Improved techniques for detecting the presence of brodifacoum in animal tissue are now available [32].

The exposure levels (percentage of home range treated) of those screech-owls trapped in January (one to two months posttreatment) for residue analysis were not known by the capturers, yet, of the six owls trapped, five had low exposures (8–12% of home range treated). The presence of detectable brodifacoum residue in three of these five birds indicates that even the less exposed owls were subject to secondary poisoning.

Habitat use

The degree of exposure to secondary poisoning for any particular owl varies depending on the amount of treated acreage within its home range, rodenticide application rates, density of vole populations, the amount of bait consumed by voles (which may be a function of application rate, vole population density and weather) and the availability of alternate (untreated) foraging areas (e.g., pastures).

Home range data are useful in defining the particular individuals and populations subject to potential poisoning from a rodenticide. Theoretically, based on the mean home range of 134 ha, screech-owls within approximately 1.3 km of a rodenticide-treated orchard would be exposed to the toxic compound. The greatest distance across any single home range of our radio-equipped screech-owls, 2.4 km, also may be used to define this "hazard zone" extending outward from a treated orchard.

The mean home ranges and habitat use determined in this study should be more reliable than those found in studies employing only hand-held antennas in night tracking. Vehicle-installed tracking systems allow greater mobility and reception range. Owls can be followed at night far more effectively, especially during rapid movements and when locating them at the extremes of their range.

The use of woodland and edge habitats by screech-owls, as noted by Smith and Gilbert [33], is consistent with our observations. Although most of the screech-owls we tracked demonstrated considerable use of woodland habitat, they also showed moderate use of open-field habitat (i.e., orchard, field-pasture). The use of orchard and field-pasture at night should be indicative of foraging behavior directed toward voles in the fall and winter and thus of the potential for secondary poisoning. However, poisoning may occur after only limited use of orchards by a screech-owl, since six of eight screech-owls with residues had negative E values for orchard. Also, in the six screech-owls found dead from apparent brodifacoum poisoning, habitat selection indices were calculated for four; three of the indices were negative for orchard.

The four barred owls radio-tracked posttreatment had a relatively large number of hectares of treated orchard within their home ranges; however, treated orchard represented less than 10% of three of these home ranges. Additionally, barred owls demonstrated limited use of orchards and a much stronger preference for woods at night than did screech-owls. Our findings on barred owl habitat agree with those of Nicholls and Warner [34], who found that barred owls were highly selective of oak woods and mixed hardwood forest and avoided open-field habitat. The barred owl is a woodland species; for that reason in particular, the secondary poisoning hazard to barred owls from orchard rodenticide treatment appears lower than that to screech-owls.

Population turnover

This study was designed to focus on the month-long interval following treatment, since we believed the principal period during which owls would consume voles that had eaten brodifacoum-treated bait would be within one to two weeks posttreatment. Brodifacoum-treated bait consumption by most meadow vole populations occurs within 24 h after the rodenticide's application [19], but death may be delayed 4 to 5 d after ingestion of a lethal dose (0.9 g Volid for pine vole, 1.8 g for meadow vole) [9]. Nontarget poisoning results when owls prey on voles (or nontarget animals) that have ingested varying levels of brodifacoum (possibly greater than the minimum lethal dose).

Merson et al. [19] stated that it is highly probable that a raptor capturing a meadow vole 24 h to two weeks posttreatment would be exposed to brodifacoum. Additional information now available indicates that second-generation anticoagulants have comparatively long biological half-lives [35]. Our estimate of the desired length of such a nontarget study posttreatment doubled when we found owls dead and brodifacoum residues in screech-owls collected up to 57 d posttreatment. Thus, the duration of the radio attachment was much more critical than we originally had anticipated.

Of the 18 previously radio-equipped screech-owls that could have been alive in May, the only one encountered was nesting in a nest box. (There was only one screech-owl nesting attempt in the 144 boxes available.) This owl also was the least exposed to brodifacoum among the 32 screech-owls tracked posttreatment. The capture of eight new individuals (seven of them with mist nets and tape-recorded screech-owl calls) in the previous territories of those 18 owls suggests considerable turnover in the population and prompt colonization of vacated territories, shifting of territories seasonally or differences in sex or age classes sampled during fall (nonnesting season) versus spring (nesting season). Besides those owls captured in May, others responded to taped calls by vocalizing or flying near the mist nets used during the capture attempts.

A portion of the mortalities in this study probably would have occurred independently of rodenticide use. Ideally, we would like to know the fall-winter mortality within the population (based on a control) and the additional mortality when rodenticide is used. The sample closest to a control population was those 12 screech-owls with the lowest exposure (less than 10% of home range treated); their mortality rate of 17% should approximate (not exceed) mortality that would have been observed over the fall and winter in a control population. This contrasts to the minimum fall-winter mortality rate of 58% observed among the 12 screech-owls with greatest rodenticide exposure. This seasonal (two to three months) mortality rate of 58% must be viewed as a highly conservative estimate, since, in several cases, the status of screech-owls at greatest risk could not be fully assessed posttreatment. VanCamp and Henny [15] determined from band recoveries that adult screech-owls in the northeastern United States and Ontario had an annual mortality rate of 33.9% and a first-year mortality rate of 69.5%.

There is no evidence that screech-owls in the northeastern United States are migratory [15]. Bent [14] stated that screech-owls are permanent residents throughout their range. Adult screech-owls demonstrate sedentary behavior and typically occupy the same nesting territory each year. Dispersal of young screech-owls in late summer and early fall is the major means of transfer among populations. However, by fall and early winter, dispersal by young-of-the-year has largely been completed [15]. Therefore, the population that we sampled in the fall, winter, and spring should have been predominantly a resident population, not subject to major changes because of dispersal or because of mortality associated with fledging and dispersal in first-year birds.

With anticoagulants, stress must be considered a factor that may influence survival. In laboratory studies, Jaques and Hiebert [36] found spontaneous hemorrhaging from anticoagulant ingestion to be a multicausative phenomenon greatly influenced and triggered by stress and other variables. Stress could occur with changing environmental conditions and season-specific behaviors (e.g., weather, prey availability, territory defense, mate choice) and may have played a role in the differential survivals in this study. Kaukeinen [9] stated, however, that animals sublethally dosed in the laboratory apparently recover completely, suggesting that the effects of hypocoagulability in the field would be completely reversible.

Other rodenticides used in Frederick County, Virginia, during our study probably did not adversely affect our radio-equipped population. Unlike brodifacoum, there was no relationship between increased exposure to zinc phosphide and potential mortality. There also is considerable evidence in the literature that zinc phosphide is not secondarily hazardous [37–39], and there is no evidence that suggests a synergistic effect between zinc phosphide and brodifacoum.

Chlorophacinone-treated areas were present at the extreme periphery of the home ranges of only two screech-owls (Nos. 19 and 36). For those two birds, only three radio locations were in chlorophacinone-treated areas. Chlorophacinone, also an anticoagulant, apparently is not as toxic as brodifacoum [8,40].

There was a relationship between screech-owl survival and the amount of brodifacoum-treated hectarage within a home range. Toward the study's end (more than 40 d posttreatment), birds exposed to higher levels of brodifacoum were absent; the owls accounted for were exposed to lower levels (e.g., Nos. 34, 36, 37, and 38). The likelihood of mortality or sublethal poisoning appears high in a screech-owl population closely associated with a brodifacoum-treated orchard.

The finding of a long-eared owl, apparently killed by secondary brodifacoum poisoning, indicates a potential secondary poisoning hazard to raptorial species other than screech-owls. Although predators could have been exposed by feeding on voles or nontarget animals, our data on great horned owls, long-eared owls, and red-tailed hawks were too limited to describe the specific hazards to those species. The potential risks to each of those raptors would vary because of differences in habitat use and diet.

Population maintenance

A secondary poisoning study can be divided into three distinct hierarchical levels: hazard to individuals, short-term population effects and long-term population effects [41]. This study was designed to address the first level and, if there was a hazard to individual owls, to partially address the second level. It was not designed to address the third level. A hazard to individual screech-owls was demonstrated. However, transmitter detachment from several screech-owls limited our ability to determine the extent of impact at the second level.

VanCamp and Henny [15] noted that young screech-owls have the capability to rapidly resettle depopulated areas. Additionally, screech-owl populations may be resilient enough to withstand some additional mortality resulting from rodenticide use. Therefore, maintenance of screech-owl populations may occur at some level despite rodenticide treatments. Long-term field research on population dynamics would be necessary to make this determination.

A series of mathematical manipulations has been used to describe possible changes in screech-owl populations subjected to increased mortality (such as from rodenticide baiting in orchards) and the compensation required to maintain a stable population [42]. This modeling assumes several compensatory factors (e.g., increased clutch size, increased survival, increased breeding). However, biological data are not available to support these assumptions, nor are most values reported for the compensatory factors biologically reasonable. For example, using a Leslie matrix and the annual adult mortality rate of 44%, the recruitment rate must be increased 4.1 times (from 2.2 to 9.1 fledglings per female) to stabilize the screech-owl population. Although this modeling is simplistic and uses very liberal assumptions, it predicts that population maintenance cannot be achieved at mortality rates far below those observed in this study.

The impact of increased mortality on a local population will be buffered by immigration, which may be strongly enhanced by the availability of a large total population. Also, as the population is expanded and defined over a large area, it will include a greater proportion of unexposed owls and the local population impact becomes deemphasized. Since a screech-owl population could be defined locally or regionally, or based on its entire continental distribution, the interpretation of population impact varies considerably depending upon which scale is used and the amount of time allowed for recruitment after rodenticide exposure [41].

Based on the results of this study on the natural history of screech-owls, we can make the following predictions: (a) Fall-winter turnover among screech-owls closely associated with brodifacoum-treated orchards (e.g., more than 20% of home range treated) would be at least 3.5 times that observed for a control population, with a seasonal mortality rate exceeding 60% of the population. (b) Screech-owls on the periphery of treated orchards (e.g., less than 10% of home range treated) would experience only slightly higher turnover than would a control population. (c) Territories vacated by mortality would be recolonized because of the excellent quality of woodland/edge/ grassland habitat for screech-owls. The impact on populations would be mostly localized and characterized by excessive seasonal turnover. Long-term effects on screech-owl population maintenance are unknown, but could include reduced local populations, especially with repeated exposure.

The results of this study indicate the need for concern when anticoagulant rodenticides, in particularly newer (second-generation) compounds, are used or proposed for field rodent control. When the rodent species and habitat targeted for the rodenticide also are a foraging resource for nontarget wildlife, the secondary poisoning hazard can be substantial.

Acknowledgement—We gratefully acknowledge the Virginia Commission of Game and Inland Fisheries, the excellent cooperation of orchardists and farmers on whose land we worked, and the Winchester Fruit Research Laboratory of Virginia Polytechnic Institute, whose facilities we used as our headquarters during the field research. Special thanks go to Mark H. Merson and Ross E. Byers and all those who assisted with the rodenticide treatments. We express thanks to ICI Americas, Inc., personnel for their assistance; the Section of Supporting Sciences, Denver Wildlife Research Center, for designing and building the radio transmitters; and Laurel VanCamp for advice on screech-owls. Very special appreciation goes to Raymond W. Blaskiewicz, Thomas A. Schoenberg, Paul D. Curtis and Brian W. Simmons for working as field assistants. The comments of numerous reviewers during the preparation of the manuscript are greatly appreciated. This research was funded by ICI Americas, Inc.

REFERENCES

1. **Kaukeinen, D.E.** 1984. *Microtus* problems and control in North America and the development of Volid rodenticide. In A. Dubock, ed., *Proceedings*, Conference on the Organisation and Practice of Vertebrate Pest Control, Elvetham Hall, Hampshire, U.K., 30 August-3 September, pp. 589–618.
2. **Pearson, K.** and **C.G. Forshey.** 1978. Effects of pine vole damage on tree vigor and fruit yield in New York apple orchards. *HortScience.* **13**:56–57.
3. **Sullivan, W.T., Jr., T.B. Sutton** and **D.W. Hayne.** 1980. Apple tree mortality rate and causes. *Proceedings*, Eastern Pine and Meadow Vole Symposium, Henderson, NC, 21-22 February, Vol. 4, pp. 62–65.
4. **Byers, R.E., M.H. Merson** and **S.D. Palmateer.** 1982. Control of orchard voles with broadcast baits. *J. Am. Soc. Hortic. Sci.* **107**:613–619.
5. **Kaukeinen, D.E.** and **M. Rampaud.** 1986. A review of brodifacoum efficacy in the U.S. and worldwide. *Proceedings*, Vertebrate Pest Conference, San Diego, CA, 4-6 March, Vol. 12, pp. 16-50.
6. **Evans, J.** and **A.L. Ward.** 1967. Secondary poisoning associated with anticoagulant-killed nutria. *J. Am. Vet. Med. Assoc.* **151**:856–861.
7. **Savarie, P.J., D.J. Hayes, R.T. McBride** and **J.D. Roberts.** 1979. Efficacy and safety of diphacinone as a predacide. In E.E. Kenaga, ed., *Avian and Mammalian Wildlife Toxicity*. STP 693. American Society for Testing and Materials, Philadelphia, PA, pp. 69–79.
8. **Mendenhall, V.M.** and **L.F. Pank.** 1980. Secondary poisoning of owls by anticoagulant rodenticides. *Wildl. Soc. Bull.* **8**:311–315.
9. **Kaukeinen, D.E.** 1982. A review of secondary poisoning hazard to wildlife from the use of anticoagulant rodenticides. *Proceedings*, Vertebrate Pest Conference, Monterey, CA, 23-25 February, Vol. 10, pp. 151–158.
10. **Townsend, M.G., M.R. Fletcher, E.M. Odam** and **P.I. Stanley.** 1981. An assessment of the secondary poisoning hazard of warfarin to tawny owls. *J. Wildl. Manage.* **45**:242–248.
11. **Hegdal, P.L.** and **R.W. Blaskiewicz.** 1984. Evaluation of the potential hazard to barn owls of Talon (brodifacoum bait) used to control rats and house mice. *Environ. Toxicol. Chem.* **3**:167–179.
12. **Colvin, B.A.** 1984. Barn owl foraging behavior and secondary poisoning hazard from rodenticide use on farms. Ph.D. thesis. Bowling Green State University, Bowling Green, OH.
13. **Craighead, J.J.** and **F.C. Craighead, Jr.** 1956. *Hawks, Owls and Wildlife*. Stackpole Co., Harrisburg, PA.
14. **Bent, A.C.** 1938. Life histories of North American birds of prey. U.S. Nat. Mus. Bull. No. 170, pp. 243–263.
15. **VanCamp, L.F.** and **C.J. Henny.** 1975. The screech owl: Its life history and population ecology in northern Ohio. North American Fauna No. 171. U.S. Fish and Wildlife, Washington, DC.
16. **Errington, P.L.** 1932. Food habits of southern Wisconsin raptors: Part I. Owls. *Condor* **34**:176–186.
17. **Stewart, P.A.** 1969. Prey in two screech owl nests. *Auk* **86**:141.
18. **Wilson, K.A.** 1938. Owl studies at Ann Arbor, Michigan. *Auk* **55**:187–197.
19. **Merson, M.H., R.E. Byers** and **D.E. Kaukeinen.** 1984. Residues of the rodenticide brodifacoum in voles and raptors after orchard treatment. *J. Wildl. Manage.* **48**:212–216.
20. **Berger, D.D.** and **H.C. Mueller.** 1959. The bal-chatri: A trap for birds of prey. *Bird-Banding* **30**:18–26.
21. **Smith, D.G.** and **D.T. Walsh.** 1981. A modified bal-chatri trap for capturing screech owls. *N. Am. Bird Bander* **6**:14–15.
22. **Stewart, R.E., J.V. Cope** and **C.S. Robbins.** 1945. Live trapping hawks and owls. *J. Wildl. Manage.* **9**:99–104.
23. **Meng, H.** 1971. The Swedish goshawk trap. *J. Wildl. Manage.* **35**:832–835.
24. **Fitzner, R.E.** and **J.N. Fitzner.** 1977. A hot melt glue technique for attaching radiotransmitter tail packages to raptorial birds. *N. Am. Bird Bander* **2**:56–57.
25. **Bruggers, R., J. Ellis, J. Sedgwick** and **J. Bourassa.** 1981. A radio transmitter for monitoring the movements of small passerine birds. *Proceedings*, Third

International Conference on Wildlife Biotelemetry, Laramie, WY, 27–28 July, Vol. 3, pp. 69–79.
26. **Hegdal, P.L.** and **B.A. Colvin.** 1986. Radiotelemetry. In A.Y. Cooperrider, R.J. Boyd, and H.R. Stuart, eds., *Inventory and Monitoring of Wildlife Habitat.* U.S. Department of the Interior, Bureau of Land Management Service Center, Denver, CO, pp. 678–698.
27. **Hegdal, P.L.** and **T.A. Gatz.** 1978. Technology of radio-tracking for various birds and mammals. PECORA IV. Symposium on Application of Remote Sensing Data to Wildlife Management, Sioux Falls, SD. *Nat. Wildl. Fed. Sci. Tech. Ser.* 3:204–206.
28. **Ivlev, V.A.** 1961. *Experimental Ecology of the Feeding of Fishes.* Yale University Press, New Haven, CT.
29. **Koubek, K.G., J.P. Ussary** and **R.E. Haulsee.** 1979. High pressure liquid chromatographic determination of the rodenticide brodifacoum in rat tissue. *J. Assoc. Off. Anal. Chem.* **62**:1297–1301.
30. **Osweiler, G.D., T.L. Carson, W.B. Buck** and **G.A. Gelder.** 1985. *Clinical and Diagnostic Veterinary Toxicology.* Kendall/Hunt Publishing Co., Dubuque, IA.
31. **Rammell, C.G., J.J.L. Hoogenboom, M. Cotter, J.M. Williams** and **J. Bell.** 1984. Brodifacoum residues in target and non-target animals following rabbit poisoning trials. *N.Z. J. Exper. Agric.* **12**: 107–112.
32. **Hoogenboom, J.J.L.** and **C.G. Rammell.** 1983. Improved HPLC method for determining brodifacoum in animal tissues. *Bull. Environ. Contam. Toxicol.* **31**:239–243.
33. **Smith, D.G.** and **R. Gilbert.** 1984. Eastern screech-owl home range and use of suburban habitats in southern Connecticut. *J. Field Ornithol.* **55**:322–329.
34. **Nicholls, T.H.** and **D.W. Warner.** 1972. Barred owl habitat use as determined by radiotelemetry. *J. Wildl. Manage.* **36**:213–224.
35. **Parmer, G., H. Bratt, R. Moore** and **P.L. Batten.** 1987. Evidence for a common binding site in vivo for retention of anticoagulants in rat liver (Abstr.). British Toxicology Society Meeting, Oxford, England, 26–27 March, *Human Toxicol.* (in press).
36. **Jaques, L.B.** and **L.M. Hiebert.** 1972. Relation of stress to hemorrhage in laboratory animals. *Proceedings*, Animal Care Technology, CALAS, Edmonton, Canada, pp. 37–52.
37. **Bell, H.B.** and **R.W. Dimmick.** 1975. Hazards to predators feeding on prairie voles killed with zinc phosphide. *J. Wildl. Manage.* **39**:816–819.
38. **Schitoskey, F., Jr.** 1975. Primary and secondary hazards of three rodenticides to kit fox. *J. Wildl. Manage.* **39**:416–418.
39. **Stieninger, F.** 1952. Rodent control and secondary poisoning of birds of prey and owls. *Ornithologische Mitteilungen* **4**:36–39.
40. **Ashton, A.D., W.B. Jackson** and **H. Peters.** 1985. Comparative evaluation of LD_{50} values for various anticoagulant rodenticides. In C.G.J. Richards and T.Y. Ku, eds., *Control of Mammal Pests.* Taylor and Francis Ltd., London, pp. 187–197.
41. **Colvin, B.A.** and **P.L. Hegdal.** 1987. Procedures for assessing secondary poisoning hazards of rodenticides to owls. In R.W. Bullard and S.A. Shumake, eds., *Test Methods for Vertebrate Pest Control and Management Materials.* American Society for Testing and Materials, Philadelphia, PA (in press).
42. **North, P.M.** 1985. A computer modelling study of the population dynamics of the screech owl (*Otus asio*). *Ecol. Model.* **30**:105–143.